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Lake Quinsigamond Urban Runoff Project
Alternatives for Stormwater Pollution Control

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LAKE QUINSIGAMOND URBAN RUNOFF PROJECT

Submitted to:

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This report, the fourth in a series, examines the possibilities of stormwater pollution control. The variety of possible controls is screened and specific possibilities selected for the Quinsigamond watershed. These control strategies are further examined in terms of their potential for meeting lake water quality goals, and their relative costs.

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Lake Quinsigamond
Urban Runoff Project

by

William C. Pisano, Ph.D
John Rhodes

Submitted to:

Department of Environmental Quality Engineering
State of Massachusetts

Environmental Design & Planning, Inc.
19 Fordham Road
Allston (Boston), MA 02134

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CHAPTER ONE

Conclusions and Recommendations

The study of Lake Quinsigamond and its watershed has culminated in extensive information pertaining to urban stormwater pollution and its impact on lake water quality. Previous reports have analyzed this data (1 through 5) in terms of the quality of urban runoff and the dynamics of the lake and its ecosystem. The intention of this report is to tie together the information concerning runoff and lake response, and to assess the possibilities of stormwater control to meet lake water quality objectives.

Conclusions

(1) Stormwater runoff in the Lake Quinsigamond watershed is a major source of lake pollution. The pollution is most extensive for particulates and for parameters associated with particulate solids. The generation of sand bars and filling-in of shallow water areas is extensive. Pollutants such as phosphorous are associated with non-dissolved solids in high proportions. Dissolved constituents are heavily present in stormwater flows although dry weather flows also contribute significant amounts. Such pollutants as nitrogen in various forms and dissolved phosphorous are significant. Heavy metals are present in runoff in relatively small quantities. Bacteria related pollution is widespread in storm water runoff.

(2) Although there is a strong negative response in the lake to stormwater loadings, Lake Quinsigamond has been blessed with substantial buffering capacity against stormwater pollutants. The abundance of iron to precipitate phosphorous and deep lake depths have maintained the recreational uses in the face of urbanization in the watershed. Still, dissolved oxygen problems arise in the hypolimnion as a result of nutrient loads. These problems limit the fish habitat and encourage recycling of bottom sediment metals. Bacterial pollution is indicated following a storm event. Deposition in the areas of storm drains is causing boating hazards and esthetic concerns. Although transparency is generally good, there is a significant decrease in transparency following a rain event. Weed growth and deposition in the shallow parts of the lake and in Flint Pond are limiting recreational activities. Water transparency is reasonable, algae in the surface layers are reasonably limited, and eutrophication does not appear to be worsening except in the shallow areas where weeds dominate. Much of the good news is a result of consertive efforts in the past ten years to eliminate industrial and sanitary waste contamination.

(3) Dissolved phosphorous was identified as a key to the rate of eutrophication and the hypolimnetic dissolved oxygen depletion rate. Dissolved phosphorous concentrations were determined to be uniform over the watershed. Particulate phosphorous control will have only a minimal immediate impact on the dissolved oxygen problem although such control may help more in the long run by reducing sediment phosphorous and subsequent weed growth and decay. Significant improvement in hypolimnetic dissolved oxygen levels would require a 50% reduction in dissolved phosphorus which is beyond the potential reduction possible through stormwater control.

(4) Suspended solids and associated pollutant loadings are heaviest on the Worcester side of the lake where the greater ground slopes provide greater scouring capacity. The swampy areas and small ponds intercepting tributary flows in other parts of the watershed may be important in reducing particulate loadings.

(5) Bacterial related pollution is widespread in the watershed. Fecal coliform levels indicate that sewage contamination is still occurring throughout the watershed.

(6) Nutrient control has little immediate potential to control weeds in the shallow parts of the lake and Flint Pond. Dredging with concern for limiting further deposition is indicated.

Recommendations

(1) End-of-pipe particulate solids control is not recommended for nutrient control at the present time. Before such control is considered, the bio-availability of particulate phosphorous should be directly measured to better determine the importance of particulate phosphorous to the lake dissolved oxygen problem. If the importance of particulate phosphorous is determined to be significantly more important than this study has assessed it to be, then particulate control should be considered on the Worcester side of the lake where solids are higher.

Local problems may suggest the need for particulate control to eliminate sand bar formation or remove sediment from more concentrated pollution sources such as quarries. Additionally, particulate control will improve lake water transparency following a rain event and might be considered for this purpose.

(2) Sewage contamination appears widespread in the watershed and a rigorous program of identifying and correcting such contamination is indicated. Past success has been

significant and future success will be more difficult as the remaining sources of sewage contamination may be hard to rectify. Disinfection of stormflows should be considered at a future point if contamination sources can not be eliminated, and more extensive lake monitoring substantiates the post storm threat.

(3) Storm runoff volume reduction through diversion to groundwater should be considered where possible. In particular flow retardation in groundwater recharge areas may provide reductions in dissolved phosphorous loadings. Limits on the degree of impervious surfaces in new developments is desirable.

(4) Local ordinances and management practices should be considered to reduce pollution accumulation in the watershed if such actions have not already been taken. Objectives should include the control of fertilizer usages, regular garbage and leaf pickup, reduction in pet feces allowed to remain on the ground and catchbasin cleaning.

(5) In-lake controls should be considered for both Lake Quinsigamond and Flint Pond. Aeration of the three main basins in Quinsigamond should be considered to extend the hypolimnetic dissolved oxygen through the critical lake summer period. Dredging and re-routing of stagnate portions of Flint Pond should be considered if the weed infested areas are to be opened for recreational uses.

Recommendations for Further Study

Further information will be helpful in making decisions concerning controls and impacts on Lake Quinsigamond. These recommendations are as follows:

(1) Bacterial pollution sampling of lake water following rain events. This sampling should incorporate finer spatial and temporal scales to better identify the extent of the pollution following storm events.

(2) Direct measurement of the biological availability of particulate phosphorous.

(3) Toxic metals lake sediment profiles.

(4) Measurement of the extent of metal recycling by analysis of metal content in fish.

(5) Sediment nutrient profiles in areas where dredging is being considered.

(6) Identification of the extent of leakage from house connections and septic systems.

CHAPTER TWO

Introduction

2.1 Purpose

This report is the fourth in a series of reports dealing with a comprehensive assessment of storm related pollution in the Lake Quinsigamond watershed. The first report (3) presented the lake discretization study, preliminary runoff model development, and the preliminary analysis of the lake response to pollution loadings.

The second report (4) presented the primary environmental and stormwater data collected in the Quinsigamond watershed over the summer and fall of 1980. The report presented the reduced data in summary statistics, presented the calibration of the stormwater runoff model, and the simulation results of annual wet weather lake loadings for 12 years. The third report (5) presented the lake response to the pollution loadings identified in the second report. This third report reviewed water quality objectives and developed target pollution reductions to meet the water quality objectives.

This report examines the possibilities of stormwater pollution control. The variety of possible controls is screened and specific possibilities selected for the Quinsigamond watershed. These control strategies are further examined in terms of their potential for meeting lake water quality goals, and their relative costs.

2.2 Background

The Lake Quinsigamond Basin has benefited from nearly complete abatement of point source discharges within recent years. This abatement has been in the form of actual elimination of point sources by the construction of interceptor sewers and transmission lines which convey the wastewaters out of the basin and southward to a regional treatment facility. This has done much to improve the quality of tributary streams in the basin and reduce public health hazards in the streams and lake.

However, in spite of the abatement of point sources, survey data indicate that certain pollutiona indices have shown little improvement over the abatement period. In particular, the trophic status of the lake has, by certain measures, shown little change. In addition, dissolved oxygen in the portions of the lake depths below the surface layer (hypolimnion) is depleted for critical periods in the late summer. This reduces the capacity of the lake to support fish and encourages recycling of metals

from the lake bottom. These problems were thought to be a result of the urban runoff nutrient and BOD loads, which have replaced the point source loads as the urbanization and point source abatement have proceeded simultaneously. Substantial growth is projected for the basin, and the question of what the ultimate impact will be on the lake is one of extreme importance.

Eutrophication and hypolimnetic dissolved oxygen depletion are regarded as the most severe problems potentially facing the lake. Eutrophication is one of the most severe forms of pollution, and affects virtually all water uses. When a lake receives plant nutrients (principally phosphate and nitrate), the nutrients tend to accumulate in the lake, which naturally becomes more eutrophic as a result. The accumulation rate is increased by the addition of extra nutrients. The nutrient input to Lake Quinsigamond has been unnaturally high for many years. Hypolimnetic dissolved oxygen depletion is also a result of nutrient loads and their capacity to support algal populations.

2.3 Report Organization

Chapter two summarizes the salient characteristics of the lake response to pollution loadings. This subject was treated in detail in a previous report (5).

Chapter three analyzes the stormwater pollution sources in the watershed as they relate to lake water quality responses. The chapter assesses the distribution of loads, the quality of the pollutants, and the ultimate sources of the contamination.

Chapter four considers stormwater controls and other related controls that may be effective in relieving the lake's water quality problems. Recommendations for future actions are developed on the basis of this assessment.

2.4 Review of Lake Response to Pollution Loadings

An in-depth analysis of the Lake Quinsigamond and Flint Pond reaction to pollution loadings was completed by Meta Systems (5). The analysis utilized a "batch" phosphorous model to simulate the most important interactions affecting dissolved oxygen and algal populations in the lake. The analysis used the most recently available data of pollution loadings including the estimates based on EDP's stormwater runoff monitoring program (4). The purpose of the next three sections is to summarize the results of the lake response analysis as they relate to possible control strategies.

Lake Quinsigamond apparently owes much of its relative cleanliness in the midst of an urban setting to its morphology.

The main lake is composed of three relatively deep basins. In addition there is an ample supply of iron and manganese compounds which are significant in reducing biologically available phosphorous necessary to support algal populations. Because of its depth and favorable chemistry the lake has a large buffering capacity against pollutants typical in urban settings such as phosphorous.

In contrast Flint Pond lacks the depth of Lake Quinsigamond and is consequentially prone to weed growth. The pond apparently benefits from the other factors buffering the lake as its eutrophication state (as indicated by parameters other than weed populations) is similar to Quinsigamond.

Inspite of Lake Quinsigamond's buffering capacity, dissolved phosphorus concentrations are sufficient to maintain an algal population capable of causing elimination of hypolimnetic dissolved oxygen during critical summer periods. Unfortunately, as will be discussed in chapters three and four, these dissolved phosphorus levels cannot be controlled to a significant level by stormwater control. Other water quality problems including bacterial related pollution and sand bar formation are amenable to stormwater control and recommendations will be developed in later chapters.

2.5 Water Quality Indicators - This section presents a summary of Water Quality Indicators developed in detail in the lake analysis (5).

Eutrophic Indications

Eutrophication has been a primary concern. The 1972 study (1) sites numerous indices to suggest advanced eutrophication of the lake and concern mounted that the situation may be worsening. The recent data (1977-1980) suggests a late mesotrophic-early eutrophic state judging from eutrophication indices based on phosphorous, chlorophyll-a and transparency measurements. Unfortunately these indicators are subject to temporal variations such as storms. Although recent data were sorted by temporal periods anticipated to be important, previous data could not be sorted in the same manor. As a result it is difficult to judge the direction or rate of the eutrophication process. From what can be discerned from the data, there is no sign of increasing euthrophication in the lake.

The data also gives no indication that the conditions in Flint Pond regarding eutrophication are substantially different than Lake Quinsigamond. The eutrophication state of Flint Pont would be determined as late mesotrophic - early eutrophic except

for the presence of weeds in the shallow waters which prompts a classification of eutrophic.

Hypolimnetic Water Quality

Stratification in the lake occurs generally about mid-April and lasts until November (approximately 200 days). During this period the lower portions of the lake lose the dissolved oxygen acquired during the winter overturning. The anoxic conditions that develop are important in reducing the habitable volume of water available for cold water fish, and in increasing the recycling of metals and possibly nutrients from the bottom sediments. In 1980 the hypolimnion turned anoxic in early July for the deep northern basin, late May for the middle basin, and mid-May for the lower basin. Analysis of data indicated similar problems for other years.

The anoxic condition in the hypolimnion is expected to release phosphorous from the bottom sediments which could play an important role in the algal colonies in the oxygenated surface layers. Released nutrients migrate upwards through mixing during storms or after the winter turnover. The presence of substantial amounts of iron and manganese is expected to minimize this occurance by precipitation of phosphorous that would otherwise reach the upper layers and be available for algae growth.

Bacteria

In general fecal coliform, total coliform and fecal streptococci samples have not significantly violated Class B water quality standards. No violations were observed in Flint Pond. Only two violations out of 104 samples for 200 colonies per ml fecal coliform standard were found in Lake Quinsigamond. Bacteria were noted to be worse in the area of Route 9 where the Belmont Street drain (Rt.9-P3), Tilly Brook (P6), and Fitzgerald Brook (Anna Street-P4) are prime contributors. The bacteria pollution status was also noted to significantly worsen following rain events. Better temperal and spatial coverage of sampling in the vicinity of storm drains may uncover local violations of bacteria standards, particularly following rain events.

Transparency

The Massachusetts state guideline for the observance of the secchi disc at a depth of 4 feet (1.22 meters) is based upon safety considerations for bathing. Both the monitoring data and water quality simulations indicate that Lake Quinsigamond and Flint Pond meet this guideline's limits. However, significant decreases in transparency has been observed following storm events. Algae cycles are the major controlling factors of lake

transparency. Suspended solids from the tributaries also contribute to a significant degree. Approximately 25% of the present opaqueness can be attributed to suspended solids.

Weeds

Weed growth is problematic both in Flint Pond and in the shallow areas in the northern lake, north of Lincoln Street. As the reservoir for plant nutrients is the bottom and is presumably abundant, water quality control is likely to have no effect on weed growth. Dredging would be required to remove weeds.

2.6 Parameter interactions

The lake response analysis (5) assessed a number of important chemical and physical interactions and identified those mechanisms that were most important in sustaining undesirable water quality. Eutrophication and the development of anoxic hypolimnetic conditions are the water quality problems of greatest concern in the lake. Dissolved oxygen appears to be the most significant variable limiting the cold water fish habitat to upper layers of the lake. The critical period is in August and September. This dissolved oxygen depletion could be reduced by reducing the lakes nutrient loading and subsequently the oxygen demand of decaying algae.

To control algal cycles, phosphorous was identified as the limiting factor. The N:P ratios for most of the year are greater than the 7:1 ratio found in algae biomass. Short periods of lower N:P ratios were linked to summer storm periods when runoff contributed nutrients at N:P ratios of less than 4:1. The reversal may be important for short periods however the reversals of the N:P ratio were considered less important than the long term importance of available phosphorous. This conclusion is supported by the settling column results (4) which show runoff nitrogen to settle more slowly than phosphorous and therefore the N:P ratio will quickly increase as phosphorus settles out.

Dissolved phosphorous was determined as the dominant form biologically available for algal growth. Particulate phosphorous apparently plays a very minor direct role. Investigations reported in the literature suggest particulate phosphorous will generally settle at too fast a rate to be useful to algae in the upper levels of the lake. The abundance of iron in the lake will insure settling of phosphorous by forming iron phosphate which will readily settle. In addition particulate phosphorus is more stable than particulate nitrogen and therefore the rate at which particulate phosphorus can be converted to a biologically available form is less. Though repeated model runs using the model developed for the lake analysis and a number of other

models that have been developed for similar kinds of analysis, the bio-availability of particulate phosphorous was noted as being very low to fit the existing data. Sensitivity runs using the lake model showed dissolved oxygen and other parameters to be more sensitive to dissolved phosphorous levels than to particulate phosphorous.

2.7 Pollution Sources

Nutrients

Estimates of average total loads to the lake indicate that wet weather flows provide the greatest amount of suspended solids and total phosphorous. Non-storm contributions (base flows and atmospheric loadings) play a much larger role in the case of dissolved phosphorous and total nitrogen. The following table (Table 2-1) summarizes these estimates (5).

Table 2-1 Average Annual Pollution Loads

	atmos.	base flow	storm flow	units
TSS	-	43	781	metric tons/yr
TN	2940	20500	16000	kg/yr
TP	88	750	4120	kg/yr
DP	88	460	810	kg/yr

Internal regeneration of phosphorous may be a significant means of indirectly providing particulate phosphorous in an available form for algae growth. Because of the unfavorable Fe:P ratios and the relatively sheltered settling of the lake, regeneration of phosphorous from bottom sediments through wind mixing or spring overturn does not appear significant. Phosphorus regeneration from shallower areas where weed growth is abundant may be more significant. This process can occur through the uptake of sediment phosphorous by weeds which eventually decay and release dissolved phosphorous. This mechanism may be important in the northern portion of the lake above Lincoln Street where the mouths of Poor Farm Brook and Newton Pond outlet are located, and in Flint Pond.

Bacteria

The highest coliform concentrations have been found around Route 9 and in the northern basin, with higher concentrations generally after a storm event. As high coliform counts were found in storm flows from the Belmont Street drain (Rt. 9), Tilly Brook and Fitzgerald Brook (Anna Street all in the immediate

vicinity of Route 9), the bacteria results are not surprising. Known sewage contamination in Poor Farm Brook may also be a major cause. Finer spatial and temporal sampling coverage would be necessary to identify the extent of the danger, particularly following rain events.

Heavy Metals

Sediment samples indicate substantial metal buildup. There is a resulting concern that harmful metals are being recycled from the sediments through fish populations. Anoxic conditions will increase the recycling of heavy metals by lowering the pH of the hypolimnion and altering the redox potential. As a result dissolved oxygen conditions in the hypolimnion are of concern to regenerating metals loadings from the bottom sediments.

2.8 Stormwater Sampling Locations

Stormwater flows and water quality samples were monitored at six primary sampling sites during the summer and fall of 1980 (4). The flows were measured with continuous recording charts. Discrete water quality samples were taken over the course of rain events to enable precise tracking of loading variations with flows. Settling column samples were also taken at selected sites (Belmont Street drain and Fitzgerald Brook) to better assess the settling potential of water quality constituents. Parameters covered by the sampling program included particulates (suspended solids, total solids, volatile fractions), nutrients (phosphorous- dissolved and total, nitrogen in different forms) COD and heavy metals (Cd, Cr, Cu, Pb, Fe, Mn, Ni, Zn and As).

Figure 2-1 designates the locations of these sampling stations. The stations are as follows:

Station Name	Tributary Name	Code
Jordan Pond	Inlet to Jordan Pond	P1
Route 9	Belmont Street storm drain	P2
Locust St.	Tributary to Belmont st. drain	P3
Anna St.	Fitzgerald Brook	P4
Convent	Tributary to Coal Mine Brook	P5
Tilly Brook	Tilly Brook	P6

The figure also identifies secondary sampling sites (S1-S9) where very limited data was collected for 1980. The sites are the targets of more extensive data collection in 1981.

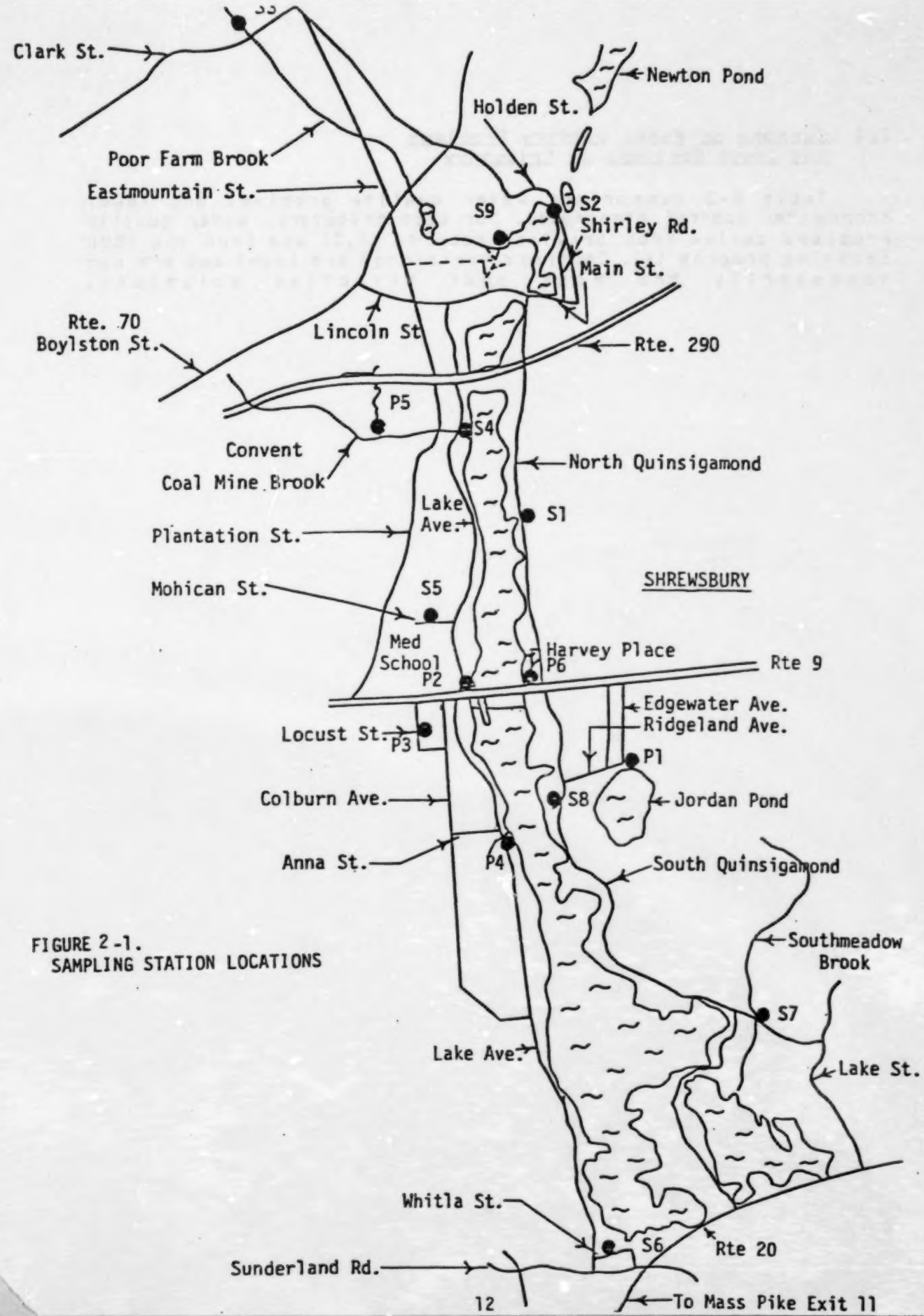

FIGURE 2-1.
SAMPLING STATION LOCATIONS

2.9 Summary of Water Quality Problems and Ideal Controls by Tributary

Table 2-2 summarizes water quality problems and ideal stormwater control strategies. For each tributary, water quality problems derive from previous reports (1,3) and from the 1980 sampling program (4). Controls envisioned are ideal and are not necessarily the most cost effective solutions.

TABLE 2-2

Summary of Tributary Water Quality Problems and Ideal Solutions

Tributary or Storm Drain	Water Quality	Ideal Control
Belmont St. Storm Drain (Route 9)	High storm solids, particulate phosphorus highest fecal coliform levels, moderate metal loads.	High rate particulate control, disinfection. Locate & eliminate sewage contamination
Medical School Storm Drain	High solids during construction.	No action Construction runoff control for future construction projects in basin
Coal Mine Brook	Evidence of sewage contamination.	Identify & correct sewage contamination
Commercial area tributary to Coal Mine Brook (Convent)	Moderate storm solids, particulate phosphorus, and metals. Low fecal coliform.	No action
Poor Farm Brook	Low DO levels, moderate solids and nutrient loads, high fecal coliform. Weeds at mouth. Large catchment with significant background loads.	Aerate City Farm Pond to increase DO. Eliminate sewage contamination, disinfect if necessary after elimination. Investigate dredging of weeds. Baffle system in City Farm Pond to remove solids, volume reduction through artificial recharge
Newton Pond Outlet	Best water quality, evidence of low DO. Weeds at mouth.	Monitor DO, investigate dredging of weeds
Billings Brook	Past high levels, inorganic solids, BOD and phosphorus (sources: quarry, Dairy Co., landfill).	If necessary solids control from quarry. Reduce perculation through landfill.
Tilly Brook	Large catchment with significant background loads. Moderate storm solids. High fecal coliform.	Identify and correct sewage contamination then disinfect if necessary. Alleviate hydraulic blocks to moderate flows.
Jordan Pond Outlet	Infrequent flow, high retention time in Jordan Pond.	No action for Quinsigamond- effects on Jordan Pond should be examined
S. Meadow Brook	Moderate solids and nutrient levels, past evidence of sewage contamination, weeds at mouth.	Investigate dredging in Flint Pond

TABLE 2-2 (continued)

Tributary or Storm Drain	Water Quality	Ideal Control
Bonnie Brook	Past contamination from Wyman Co. with continuing intermittent oil contamination. Outlet sediments considered very poor quality.	Investigate dredging of outlet. Eliminate discharge from Wyman Company
O'Hara Brook	Intermittent flows. Past evidence of sewage contamination	Locate and correct sewage contamination
Bridle Path Storm Drain	Limited Data	Monitor water quality for sewage contamination
Bird Street Brook	Minimal flows in spring past evidence of sewage contamination	Locate and correct sewage contamination
Fitzgerald Brook (Anna Street)	High solids and nutrient loadings High fecal coliform & COD levels	High rate particulate control and disinfection. Locate and eliminate sewage contamination
Total watershed	High, uniformly distributed dissolved phosphorus levels. High fecal coliform levels.	Volume reduction through impervious control and diversion to groundwater or to Blackstone River wherever possible. Reduce fertilizer use, pet feces. Identify and correct sewage contamination.

CHAPTER THREE

Urban Runoff Pollution Sources

Lake Quinsigamond is unique in that it provides a complete range of water recreation in a highly urbanized setting. As discussed in the previous section, the primary pollution loadings to the lake are carried to the lake by stormwater runoff. Understanding the sources and quality of the stormwater contamination is essential in establishing control alternatives. This section examines the sources of pollutants in stormwater runoff identified as key parameters to lake quality: suspended solids, nutrients, heavy metals and bacterial/viral pollutants.

3.1 Sediments

Sediment pollution causes negative impacts through both direct and indirect means. In a direct fashion the formation of sandbars in the area of outfalls cause boating hazards and unsightly appearances along the lake. The Route 9 area is an example of this problem. In addition, deposition in the storm conduits can cause decreased hydraulic capacity and blockages. Lake transparency is also decreased by sediments carried by stormwater particularly during the periods following significant rain events. Indirect impacts depend on the degree to which other pollutant sources can be attributed to particulates. In general, particulates will act as transporters of other pollutants such as heavy metals and nutrients.

Over 95% of the total suspended solids loading (in essence the non-dissolved solids fraction) comes to Lake Quinsigamond via storm runoff (see Table 2-1). Only a small fraction of the solids loading is carried to the lake during weather flow conditions. A major reason for this is that the storm flows are better able to scour solids from the ground or deposits within the drainage system.

The areas in the Quinsigamond watershed that generate storm flows with greatest scour potential are also the areas with the heaviest solids loadings. The Worcester side of the lake (directly west) has significantly greater slopes than are found on the Shrewsbury side or in the northern or southern areas. As a result, storm runoff on the Worcester side is more rapid with greater scour potential than elsewhere in the watershed. Solids are more easily scoured, suspended in the runoff, and delivered to the lake.

Review of the stormwater monitoring data clearly show the impact of differing topography on both the runoff hydrographs and the pollution content. Three areas were continuously monitored in Worcester where slopes are relatively high: Belmont Street drain (Rt.9 - P2), Fitzgerald Brook (Anna St. - P4) and Locust Street (P3, tributary to the Belmont Street drain). Tilly Brook (P6) and Jordan Pond inlet (P1) were monitoring sites representative of Shrewsbury and its lower slopes. The Convent (P5, parking lot drainage to Coal Mine Brook) although on the Worcester side, has relatively lower slopes. Poor Farm Brook (S9,flow gaged only) drains lower sloped lands similar to Tilly Brook.

The hydrographs of the monitored sites in the high sloped areas show runoff to rise quickly after the start of rain, fluctuate with high and low flows and then fall off quickly at the end of a rain. On the other hand, Tilly Brook and Poor Farm Brook rise much more slowly, intense fluctuations buffered and hydrograph tails long and slow to drop. Jordan Pond and the Convent hydrograph characteristics lie between the above two examples as they drain much smaller areas at low slopes but without the buffering capacity of wetlands and upstream ponds.

Suspended solids concentrations are highest at the stations on the Worcester side that have high slopes. Table 3-1 demonstrates this comparison which presents the percentages attributable to each station (excluding Poor Farm Brook) of flow and pollutant loadings monitored in the sampling program. (100% is the total load monitored, not the total load to the lake). As can be seen in Table 3-1 the flow volume contribution is highest at Tilly Brook which drains a very large area, Route 9 and Anna Street are next, and the other stations represent smaller relative flow contributions. The suspended solids figures alter the pattern. Suspended solids contributions at Tilly (P6), Jordan (P1) and the Convent (P5) are much smaller in relationship to their respective flows. Route 9 (P2), Locust Street (P3) and Anna Street (P4) share higher percentages of the suspended solids contributions. These solids distribution consequences have important implications for pollutant loadings as will be discussed in the next section.

There are other factors that may be important in dictating the distribution of solids loadings. Some of these factors can be associated with land slopes such as swamping areas which can remove suspended materials before they reach the lake. There are numerous small ponds in the watershed which may be acting as sedimentation basins and remove solids before they reach Quinsigamond. Jordan Pond is an example. The pond did not overflow during the summer or fall and obviously was an effective device for preventing materials from reaching the lake

during the critical summer periods. Other ponds may have similar effects although the residence times are generally short and it is questionable if much sedimentation is occurring. Ponds such as City Farm on Poor Farm Brook, Newton Pond, and Mill Pond on Tilly Brook may be removing solids in storm flows before they reach the lake. In general it is the lower-sloped areas that have the additional benefit of ponds and swampy areas to reduce solids loadings.

3.2 Nutrients

Nutrient loadings were determined by the lake analysis to be the key to dissolved oxygen levels in the hypolimnion. The nutrients were determined to be more important than direct oxygen-demanding loads. Nutrients impact dissolved oxygen by feeding algal populations which impact dissolved oxygen through respiration and decay.

Dissolved phosphorus was identified as the nutrient limiting algal growth in most situations. Particulate phosphorus loading contributes to the problem directly, and may be more important than presently identified by regeneration of sediment phosphorus through weed decay. Nitrogen loads may also be important for short periods in the summer when nitrogen may become the limiting nutrient as opposed to phosphorous.

The particulate phosphorus loadings follow the same distributions pattern identified for suspended solids. The ratio of total phosphorus to dissolved phosphorus is 4.2:1 for total tributary loads and 5.2:1 for storm loads. These ratios illustrate that the greatest amount of phosphorus is associated with particulates. Examination of Table 3-1 demonstrates that the total phosphorus loadings for storm runoff (total phosphorus is primarily composed of particulate phosphorus) follows the same pattern as suspended solids. The highly-sloped Worcester Stations (Route 9-P2, Locust St.-P3, Anna St.-P4) contribute higher proportions of total phosphorus than their respective flow contributions. The remaining lower-sloped areas contribute lower proportions of total phosphorus.

The distribution of dissolved phosphorus does not follow the distributional pattern identified for solids. As Table 3-1 demonstrates the dissolved phosphorus loads closely follow flow for the six monitored stations irregardless of the dynamics of the flows. Dissolved phosphorus concentrations are uniform in runoff from different areas. As a result the total phosphorus: dissolved phosphorus ratios are high for the three high slope stations (7.0 for Route 9, 6.7 for Locust (P3) and 3.9 for Anna Street. For the other stations the total phosphorus: dissolved phosphorus concentrations are lower (2.4 for Jordan, 3.5 at the

Convent, and 2.2 at Tilly Brook). No pronounced impact on dissolved phosphorus loading can be discerned from the data as originating in a unique portion of the watershed. Although urban land uses have been shown to have greater dissolved phosphorus loading per acre, the loading closely follows the amount of flow that can be generated per acre.

Plotted concentration values (4) demonstrate first flush occurs at all stations for solids. In particular, total phosphorus concentrations are shown to be higher in the first few samples after the start of a rain event. On the other hand dissolved phosphorus does not show any first flush. Concentrations remain fairly constant throughout the course of the rain event. These qualitative distinctions suggest very different sources of the dissolved and particulate phosphorus. In particular, because of the lack of a first flush in dissolved phosphorus it does not appear that sediments transportable by a storm are major sources of dissolved phosphorus.

Settling column results at Rt. 9 and Anna St. show moderate settling potential for particulate phosphorus (4). Only approximately 20% of the total phosphorus was seen to settle over the course of the column test which distinguishes particle settling rates as low as 0.001 cm/sec. As the total phosphorus: dissolved phosphorus ratios for Route 9 and Anna Street are greater than 5, higher settling rates would be expected than were seen in the settling column results. However, the two storms sampled for settling column tests were not major storms and may not have generated heavy sediment loadings.

The total nitrogen loading pattern lies in between the dissolved phosphorus and sediment patterns. Only about 50% of the total nitrogen reaching the lake is delivered by storm flows. Table 3-1 suggests that total nitrogen loadings fairly well follow flows, although loadings are somewhat heavier on the Worcester side. A mild to no "first flush" can be discerned from the concentration time plots (4). No settling was discerned for nitrogen from the settling column results (4). These results are as expected as nitrogen is typically in a dissolved form or a relatively unstable particulate form. Control of total nitrogen through particulate control is less favorable than control of total phosphorus through particulate control.

3.3 Heavy Metals

Heavy metals are believed to be deposited in significant amounts in the lake bottom. Heavy metals from there can be introduced into the food change by the low oxygen, low pH conditions favoring dissolution of heavy metals. The extent of

TABLE 3-1

Loading Distribution at Monitored Sites

(percentage of total monitored load)*

	Jordan Pond P1	RT.9 P2	Locust St. P3	Anna Street P4	Convent P5	Tilly P6
Flow	4	14	7	18	7	50
TSS	2	28	12	19	2	36
Total Nitrogen	7	25	9	15	5	38
Dissolved Phosphorus	4	13	8	19	5	49
Total Phosphorus	3	25	15	21	5	31

* This table presents the percentage distribution of average storm loads between the six primary sampling stations. The loads are the average load per storm of the monitored storm events. The total of all the loads (100%) is the average total load monitored at the six stations, not the total load reaching the lake from all sources.

As catchment sizes vary for each sampling station, the flow contribution at eac station also varies substantially. The intention of the table is to demonstrate how solids related pollutants do not follow the distribution patterns for flow, whereas dissolved pollutants do have similar distribution to flow.

the metal buildup and its recycling through the lake's ecosystem are not known.

Overall heavy metal loadings of toxic heavy metals are light. There are heavier loadings of iron which is a characteristic of the iron-rich watershed. Lead is also relatively heavy in the sections of the watershed where automobile traffic is heavy. Short periods of high metals concentrations were seen at the start of rain events at monitoring sights on the west side of the Lake (Anna St., Rt. 9, Locust St., Convent), and at Jordan Pond on the east side probably due to the portion of Route 9 that it drains. Heavy metal concentrations were consistently low at Tilly Brook.

3.4 Bacterial Related Pollution

Water quality impairment can be caused by a variety of bacteria and viruses harmful to humans. An important indication of this kind of pollution is the presence of fecal coliform bacteria that are plentiful in the waste of warm blooded animals.

High fecal coliform levels were observed at all the water quality monitoring stations except at the Convent. In all cases samples were taken with fecals in excess of 10^4 counts per ml with conditions probably the worse in samples from the Belmont Street storm drains (Route 9). These high levels indicate sewage contamination is occurring in all the catchments monitored with the exception of the commercial area monitored at the Convent (P5).

The sources of the sewage contamination are likely to be numerous. In areas without sanitary sewers, septic tank leaks may be substantial. In areas with sewers, house connections have increasingly been identified as a source of sewage contamination. In general storm drains are constructed without a great deal of care to avoid infiltration and renegade sewage leaking from house connections has no difficulty reaching the storm drains. Additionally there may still be direct sewage connections draining to storm drains or major points of leakage between neighboring sanitary and storm lines. Common manholes were a problem in the past and may still be allowing some leakage.

The lake monitoring results show high bacteria concentrations in the vicinity of Route 9 and in the northern basin. The presence of high fecal levels in the storm drains on both sides of the lake near Route 9 is unquestionably causing the high values after storms. The high levels in the northern basin in general may be caused more by Poor Farm Brook where there are known sewage contamination sources.

3.5. Overall Distribution of Loads

The monitoring program gives the most accurate information as to how the pollutant loads are distributed over the Quinsigamond watershed. The runoff simulation model was designed to utilize this monitoring program to estimate annual loads for the entire watershed. Although the model is believed to have properly estimated these total loads, the model did not estimate the distribution of loads over the watershed. This result is primarily because the differences in topography and flow dynamics were not simulated in the model. These difficulties were discussed in the report on measurement and modeling (4). Inspite of the orientation toward total watershed loads the model does provide approximate estimates of the distribution of loads by major catchment. Table 3-2 presents the percentages of flow volume and pollution loads attributable to major catchments by the simulation model.

The table demonstrates the importance of the less urbanized catchments such as Poor Farm Brook, Tilly Brook, Newton Pond Outlet, and S. Meadow Brook. To a large degree these areas are composed of wetlands and forested areas. However even though the loadings per acre for these watersheds are lower than in the more urbanized areas, the loading contribution to the lake is significant. Pollution control strategies that concentrate on the urban portion of the watershed can only deal with a portion of the wet weather pollution loading problem.

Table 3-2

Distribution of Storm Loads
(percentage of total loading)

Drainage Area	Flow	TSS	Total Nitrogen	Dissolved Phos.	Total Phos.
Belmont St. Drain (Rt. 9)	6	12	11	7	8
Fitzgerald Brook (Anna St.)	8	8	6	9	9
Jordan Pond Outlet	1	1	3	2	1
Tilly Brook	11	6	6	8	6
Newton Pond Outlet	14	9	9	11	11
Poor Farm Brook	17	17	18	17	19
Coal Mine & Billings Brook	15	17	15	14	16
S. Meadow Brook O'Hara Brk. & Bridle Path Drain	21	21	24	25	21
Bonnie Brook	7	9	8	7	9

CHAPTER FOUR

Pollution Control Strategies

Analysis of Lake Quinsigamond and Flint Pond suggest that the water bodies are in good shape considering their urban setting. Problems exist which can be addressed in part by storm water and storm related controls. In Appendix I a brief review of state-of-the-art stormwater controls is presented. In this chapter those controls with applicability to Lake Quinsigamond are further discussed.

Water quality problems identified by the lake analysis and addressed through the following stormwater controls are as follows:

Dissolved Phosphorus
Particulate Phosphorus made available for biological activity
Nitrogen available for biological activities
Bacterial related pollution
Sedimentation and sandbar formation
Sediment metals and nutrient accumulations in sediment
Weed growth
Hypolimnetic dissolved oxygen

Control possibilities discussed below include the following:

Particulate controls in storm water runoff
Disinfection of runoff
Pollution accumulation control on land surfaces
Runoff volume reduction or diversion
Sewage contamination reduction
Weed control
In-lake controls

4.1 Particulate Controls

A variety of means are available to remove pollutants that are already in stormwater flows. Generally the only controls that are financially reasonable are solids separation devices. These devices include high rate separators such as swirl concentrators, or sedimentation schemes that allow natural sedimentation to occur in an area where the sediment can be removed.

Particulate control devices have proven effective at removing settleable solids and many suspended solids from stormwater flows. The problems of sandbar formation such as that found under the Route 9 bridge can be well controlled by a device on the storm drain outlet in that area. Such devices could also

serve the watershed by removing sediment from problematic flows such as quarries if no other alternative is available.

Particulate separation devices are usually designed to remove floatable pollutants by some kind of skimming device. Although floatable pollutants were apparent in past lake problems, the need to control floatable pollutants may not be essential under present conditions.

In general particle separation devices will remove other pollutants only to the degree to which they are associated with solids. Phosphorous has been strongly linked to particulates in storm flows. However, the lake analysis has indentified the dissolved portion as more important to sustaining algal populations. Nitrogen was assessed to be similar in that the removable particulate fraction was not expected to be significant. Therefore it must be concluded that although particulate removal will help the lake by reducing the particulate phosphorous loading, the gain is likely to be small in terms of reducing biologically available nutrient loadings.

A particulate separation device should first be located in the area where the particulate fraction in the runoff is highest and the overall sediment loads are significant. This requirement pinpoints the Belmont Street drain (Route 9-P2) as the most effective location for particulate control, followed by Fitzgerald Brook (Anna St-P4). However other local problems may exist that were not uncovered by the monitoring program.

Both the Belmont Street drain and Fitzgerald Brook have limited available land for particulate control. Sedimentation basins must be immediately ruled out due to the lack of space. Swirl concentrators could be located at either site, and particularly at Route 9 where the construction could be integrated with the planned construction of a new bridge.

There also appears to be sufficient space behind Ramshorn Island for Dunker's pontoon system. The approach directs storm flows through an inexpensive system of baffles to enable sedimentation to occur in a controlled area. The island allows separation between the narrow lake's boating area and the area required by the pontoon system. The pontoon system would require access from the west side of the lake for management of the pontoon system and periodic dredging of the captured solids. However, the concept is to store storm flows in the baffle system and pump the stored liquid to the sanitary sewer system. The costs of pumping to raise the water to the sanitary line on Lake Street would be excessive. Therefore this system can not be recommended.

4.2 Pollution Accumulation Control

One source of pollutants in the storm runoff is the dust, dirt and other debris that accumulates continuously in the watershed. Source control can be effective in some cases. This type of control would reduce the amount of material collecting through street sweeping, gargage pickup, fertilizer control, pet control or other means of reducing the accumulations.

For many control items coming under this heading the implementation costs are small. Therefore even though the effects are not well identified the control can be recommended in general principle. Included are controls on the private use of fertilizer, public information as to the harmfull effects of over-fertilizing, regular leaf and garbage collection and control of pets and their wastes. In particular, pet feces are increasingly identified as important sources of bacterial related pollutants and BOD. Ordinances to encourage pet owners to pick up after their pets can be significant in reducing these loads.

Other controls are more costly and their cost effectiveness must be addressed. Street sweeping is one such control. Street sweeping can reduce particulate loadings and some dissolved loadings by reducing the amount of polluting materials available along roadways. However, the area in the watershed that could be swept is small. The dissolved phosphorous loadings come from the entire watershed including the more rural areas where street sweeping is impossible. The settling column tests indicate that the dust and dirt that would be swept up by a robust sweeping program is not likely to be a significant source of dissolved phosphorous. For these reasons street sweeping does not appear to be a significant means of controlling nutrient loadings.

Catchbasin cleaning similarly may offer little relief of nutrient loadings. However catchbasins have been shown to be effective in removing particulates (6) if well maintained. Unmaintained catchbasins can become pollutant sources by resuspension and dissolution of the trapped materials. However even unmaintained catchbasins can become pollutant removers if enough material has collected to cause a filtering action. As a result of this uncertainty an operating policy concerning catchbasins is probably best based on the need to protect from clogging and flooding more than pollution removal unless the basins can be regularly cleaned.

Other areas where pollution sources may accumulate offer obvious recommendations. Landfills should be examined to minimize leaching by minimizing ponding and, if possible, ground water movement from the landfill. Quarries should be prevented from adding sediment loadings to the feeder streams as solids loadings

can be substantial from these sources. Junkyards or other waste storage sites should be examined to minimize runoff.

4.3 Volume Reduction

In situations such as in the Quinsigamond Watershed where there is no clearly identified source of a key parameter (dissolved phosphorous), then a volumetric reduction of storm flows may be necessary if loadings are to be significantly reduced. As dissolved phosphorous loadings in the basin follow flow, the amount of dissolved phosphorous reduction that can be achieved is roughly the same as the volume reduction that can be achieved. The reduction can be effectuated generally by a diversion of moisture to the ground, to the air through evaporation, or diversion around the Lake to a point downstream on the Blackstone River. Diversion to the ground water system would still enable the lake to be fed by stormwater but after the ground's filtering action.

Diversion is difficult to achieve in the watershed due to the nature and shape of the watershed. In the areas where there is swampy ground, diversion to the ground water system can not be achieved. Swamps and ponds are generally discharge points for the ground water system and it is recharge points that are needed to divert flows to the ground water system. On the Worcester side of the lake the steep slopes and urbanization limit the points that artificial recharge could be developed. There may be a few points on Poor Farm Brook or Bonnie Brook where recharge could be accomplished. However the points are likely to be upstream of major polluting land uses and therefore offering limited pollution reduction.

Diversion of water to the Blackstone River is difficult to achieve due to the long narrow shape of the lake. Major storm drains would have to be diverted through fairly long intercepting storm drains to bypass the lake. The construction cost of the intercepting drains is likely to be prohibitive.

Principals of diversion should be included in further urban development. A minimal amount of impervious land use should be allowed. By increasing the amount of pervious area, significant amounts of runoff can be diverted to the ground water system that would otherwise become storm runoff. This kind of control is unlikely to offer a means to reduce present volume, but it is essential to ward off an increase in loadings in developing areas.

4.4 Disinfection

If sewage contamination continues to be a problem in the storm drains, disinfection at the outfalls should be considered. The extent of bacterial pollution in the lake is not well known due to the scarcity of bacterial lake monitoring data. A more temporally and spacially intense sampling program is necessary to examine the impacts of storm water.

If bacterial pollution is considered a problem, three actions should be considered. In one, the beaches and recreational facilities could be closed directly following a heavy rain as a temporary action to protect public health until more information is acquired. Secondly, a rigorous program of identifying and correcting sources of sewage contamination and reducing the loading from pet feces. Thirdly (if necessary after action 2 is taken), disinfection could be designed at the major storm drains to disinfect during storm events.

4.5 Sewage Contamination Control

It is clear from the monitoring data that there is significant sewage contamination of the storm drains. Much of the source of the contamination may be sources such a septic tanks and leaking house connections. These sources may be impossible to control. However there may still be direct connections between the sanitary systems and the storm drain system. A program of dye studies and enforcement may be significant in reducing both the bacterial problems and the nutrient loading problems.

4.6 Weed Controls

Weeds are a problem particularly in Flint Pond, but also in the northern section of the lake. Weeds hinder recreational activities and may also be a significant source of dissolved phosphorous through growth and decay.

Dredging is the only means of weed control that can be recommended. Nutrient source control is unlikely to have much effect as the bottom is likely to have an abundant reservoir of nutrients to support weed growth. However in the long run nutrient loading controls may reduce the weed growth as old sediments are covered.

There is a possibility of lowering the level of Flint Pond to facilitate dredging of exposed weeds. If such an approach is considered sediment profiles should be taken to be sure that the sediments removed don't uncover a ground layer even richer in nutrients and therefore a worse situation. Having the ground

exposed during winter may also be useful to kill the root systems. Alteration of the drainage patterns in Flint Pond should be coupled with the dredging program to limit the amount of sediments that are likely to deposit following the dredging operation.

4.7 In-Lake Controls

Although it is not the intent of this report to examine in-lake controls, such an examination is useful as a comparison to storm runoff controls. In the Quinsigamond watershed it appears difficult to control the dissolved phosphorous which is the key parameter causing oxygen depletion in the hypolimnion. Therefore it may be more advisable to address the dissolved oxygen problem directly by in-lake aeration.

In-lake aeration could be effective at maintaining dissolved oxygen in the hypolimnion during the summer month critical period. Aeration during this period could increase the habitable zone for fish, and decrease the amount of metal recycling from the bottom sediments.

The lake would likely need three aerators to correspond to the three major basins in the lake. The process would need to be carefully done to avoid upsetting the temperature stratification and thereby damaging the cold water fishery.

4.8 Capability of Controls to Meet Water Quality Objectives

The water quality goals of Lake Quinsigamond are to maintain the facility for recreational contact sports. The areas of the lake and Flint Pond that have lost their recreational value would ideally be restored to their full potential.

Milestones that would represent the water quality goals were developed in a previous report (5). These milestones include:

Maintenance of Dissolved Oxygen in the hypolimnion for the entire 200 day period between turnover.
Maintenance of a 4 foot sechi depth.
Maintenance of class B coliform standards.
Elimination of objectionable sand bar deposits.
Reduction of weed growth in Flint Pond.

Hypolimnion Dissolved Oxygen

The milestone of maintaining hypolimnetic dissolved oxygen for the entire period between turnover can not be achieved

through stormwater runoff control alone. Particulate control at Route 9 and Fitzgerald Brook at best may remove 40% of the particulate phosphorous load in those tributaries and minimal amounts of the dissolved phosphorous load. This represents approximately 8% of the total lake load (excluding Flint Pond). Recharge at Poor Farm Brook may, at best, achieve 25% volume reduction which would reduce the total lake dissolved phosphorous load by 5%. Other areas may be able to prevent an increase in runoff volume but volume reduction is unlikely. If one further assumes that 10% of the total lake load of dissolved phosphorous could be reduced by street sweeping and fertilizer control, then the total dissolved phosphorous load to the lake will have been reduced by 15% depending on the success of street sweeping. Even these optimistic values fall well short of achieving the 50% to 80% reduction necessary to maintain the dissolved oxygen for wet years. For dry years the reductions may be enough to maintain dissolved oxygen depending on the availability of particulate phosphorous for biological activity. For the purposes of maintainance of dissolved oxygen levels in-lake controls should be examined.

Maintenance of 4 Foot Secchi Depth

Lake samples show that this milestone has already been passed. Maintenance of this condition is directly linked to the phosphorous loadings. The dissolved oxygen conditions in the hypolimnion appear more critical and maintenance of the secchi depth should be accomplished unless the loading conditions worsen. Local observations of the Lake suggest a notable increase in lake turbidity following a rain event. From conversations with local officials and lake users it appears that this turbidity increase is not objectionable. If it is considered objectionable, then both solids control and effective nutrient control will be helpful in reducing the impact.

Maintenance of Class B Coliform Standards

Because of limited lake sampling it is not known if significant violations of coliform standards are occuring following rain events. However the data does indicate that there may be violations in the vicinity of storm drains. If such violations are occuring then a rigorous program of identifying sewage contamination and ordinances to reduce pet feces may be sufficient to rectify the problem. If the sewage contamination is not correctable then disinfection should be considered at selected storm drains. Present information suggests that beaches should be closed following a significant storm event as a protective measure.

Sand Bar Deposits

The removal of objectionable sandbar deposits can be rectified by particulate controls at the storm drains creating the deposits. Particulate control devices are ideal for removing the heavier sediments that are responsible for such deposition.

Reduction of Weed Growth

Weed growth will probably be only minimaly impacted by stormwater control. Rather, dredging and re-channelization of lake flows should be considered as controls for weed growth. Sediment nutrient profiles should be taken before dredging is undertaken to insure that the dredging does not expose layers that are richer in nutrients. Winter exposure of the bottom can be helpful in destroying root systems.

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